Frequency-Dependent Asymptotic Analysis of Seismic Reflection from a Fluid-Saturated Medium

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RESEARCH OBJECTIVES

In this project, a linear poroelasticity model is reviewed from the point of view of basic principles of flow in porous media. A low-frequency asymptotic analysis of this model is applied to interpreting the frequency-dependent reflection coefficient component at low-frequency ranges.

The developed approach targets frequency-dependent analysis of seismic data from different types of hydrocarbon reservoirs, at both exploration and development stages. A practically important objective of this research is to demonstrate how reservoir flow properties can be mapped using the obtained asymptotic reflectivity model.

APPROACH

We derive wave propagation equations from the basic principles of the theory of filtration, particularly to verify that both the filtration and poroelasticity theories have a common foundation. In addition, such an approach facilitates establishment of a relationship between seismic imaging attributes and hydraulic reservoir parameters.

Over the last fifty years, a significant effort has been spent on investigating the attenuation of Biot's waves. In many cases, the attenuation coefficient can be obtained in an explicit, but quite cumbersome, form. Computation of the reflection coefficient is even more complex. In this study, we obtain a simple asymptotic expression, in which the role of the reservoir fluid mobility is transparent. We focus on the simplest case of p-wave normal reflection. (Solutions for more complex situations are currently under development.)

ACCOMPLISHMENTS

At low seismic frequencies, viscous fluid flow in pore space results in anomalous reflection of the signal. The reflection coefficient has been asymptotically expressed as the sum of constant and frequency-dependent components. The latter is proportional to the square root of the frequency of the signal, with the proportionality coefficient including the reservoir rock and fluid flow properties. The frequency-dependent component also includes a phase shift of the reflected wave.

In addition, we investigated the dependence of scaling on the dynamic Darcy's law relaxation time, which turns out to be linearly related to Biot's tortuosity parameter. This parameter must be very large to enter first-order asymptotic formulae. In addition, previously processed seismic data sets have been reviewed in the context of the results. In particular, 3-D seismic data from the offshore South Marsh Island reservoir have been successfully reevaluated to image hydrocarbon-rich formation layers (Figure 1).

SIGNIFICANCE OF FINDINGS

It has been demonstrated how frequency-dependent analysis can be successfully used for direct hydrocarbon indication and reservoir characterization. The analysis was performed on field seismic data from onshore and offshore hydrocarbon fields, with different properties for the reservoir rocks. Besides its use in imaging, frequency-dependent analysis based on low-frequency asymptotic scaling has great potential for quantitative reservoir characterization.

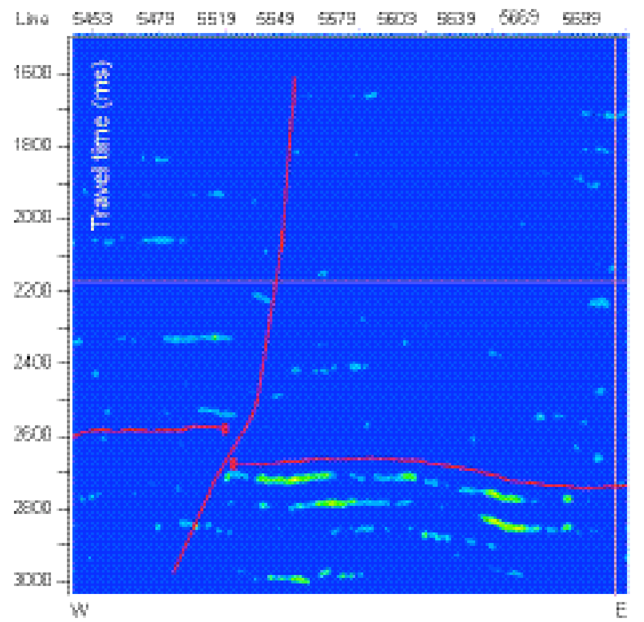

Figure 1. Imaging of the hydrocarbon-bearing zones on South Marsh Island, Gulf of Mexico, based on frequency-dependent analysis of 3-D seismic data. Conventional AVO analysis did not detect the reservoir. Data are courtesy of Fairfield Industries.

RELATED PUBLICATION

Silin, D.B., V.A. Korneev, G.M. Goloshubin, and T.W. Patzek, Low-frequency asymptotic analysis of seismic reflection from a fluid-saturated medium. Transport in Porous Media (in press), 2005. 58213

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